DESIGN OF A CONCRETE GRAIN ELEVATOR

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DESIGN OF A CONCRETE ELEVATOR

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PROGRESS IN GRAIN ELEVATOR CONSTRUCTION.

In ancient days grain was piled upon the ground, where in dry countries it was kept in a good condition for long periods. The first step toward protecting it from the weather and providing permanent places for its storage was undoubtedly made by making excavations in the ground, covering the floor and sides with stone and placing a roof of poles and thatch overhead. As man became more civilized, graineries or bins above ground where built either of stone or wood, but these constructions were generally in the form of single bins, devoid of mechanical appliances for filling and emptying, except in rare instances, as was the case with the Egyptians, of small capacity.

It was not until comparatively late years that the "cribbed" wood elevator, having a large number of small compartments, made its appearance. These structures were a vast improvement on all preceding ones, but they in turn have been displaced, and within the past ten years construction of grain elevators has evolved from stereotyped lines of simple crude woodworking to scientific designing of structures for special purposes and in more permanent materials.

The early builders of wooden elevators were resolute men of indomitable energy, but woefully lacking in scientific knowledge, who, without waiting for plans, could from the merest outline throw up by main strength a structure having a capacity of two or more million bushels in as short a space of time as thirty days. Wood was cheap and easily handled, and a few hundred feet of board more or less made no appreciable difference in cost. Mistakes could be corrected afterward. If, for instance, the walls were lacking in strength and bulged from excessive pressure, iron tie rods could be stretched across the beams. Girders and posts, if not heavy enough to carry the loads imposed, could be braced with

additional timbers, and in this way the old-fashioned method of "cut and try" went on until the wooden elevator reached a stage of comparative perfection.

But the time came when wastfulness of our forest resources, and the consequent scarcity of the supply of lumber, increased the cost of wooden elevators to such an extent, and at the same time the use of fire-resisting materials for other kinds of structures had become so general, that the desireability of building elevators which would be fireproof became more and more apparent.

The first fire-resisting elevators were built of steel, substantially on the lines of the old wooden structures which were rectangular in plan and had cribbed bins elevated on posts and arranged in rows eight or ten car lengths long.

At this point a further development took place, for it was conclusively demonstrated that previous designs and methods were unnecessarily expensive, for it was found that all machinery for unloading, handling and shipping could be more economically installed and operated in a separate building, or portion of the building, devoted entirely to this purpose and now called a "working house."

One reason for this economy is that cars may be quickly and easily unloaded from several parallel tracks into large sized car pits which discharge onto belt conveyors carrying the grain into the legs of the working house. It is evident that if the number of receiving tracks are doubled and the elevator legs diminished by half, that the working house need have only one-half the length for the same receiving capacity. This consequently makes possible a saving, not only in the first cost of the building, but also in operating as well, for it is an axiom, inany business requiring the use of machinery that the greatest return may be made from a given installation by working the machinery to its maximum intensity, thus by concentrating the handling and unloading of grain into a few legs and scales, these may be made to work more hours.

A little later it was further shown that the bulk of the grain could be stored and handled quite as readily in a cheaper annex having larger compartments.

These two developments in the primary design of grain structures were of

a radical and comprehensive nature. There have been so many other advances along scientific lines made alike in the general planning of elevators, in their machinery and equipment, and in the adaptation of a higher class of structural materials, that it has come about that the day of pioneer empiric in elevator building has passed. The materials out of which elevators, are now built, such as steel and concrete, are not only costly, but their successful use requires scientific designing and a high degree of skill in their employment. It is not only difficult, but often impossible at any reasonable cost to rectify serious blunders due to errors in design after the work is under way. Elevator designing and building is now a highly developed specialty, and a class of work which should only be entrusted to responsible specialists.

There are now several materials employed in constructing fire-resisting or fireproof elevators. Although steel makes the least risistance to fire, yet, as stated above, it was the first material to be used. There are numerous notable cases on record where steel elevators were utterly destroyed by fire originating within their own walls. Steel is a high conductor of heat, and when grain tanks are built of it, it is used in very thin sheets. This makes it unfit in many instances to protect grain from damage even though the fire is not of sufficient intensity to destroy the tanks themselves. In this way the contents of several tank elevators have been damaged to a large extent by adjacent fires, which would not have injured even a wooden elevator similarly located.

As soon as engineers reach the stage where they were able to scientifically calculate grain pressures and could consequently design elevator structures intelligently, the other types of construction, such as concrete, tile and brick, came into use. Of the three types, concrete undoubtedly will bear the closest inspection, and will pass the highest examination. When made into final structure form it has greater strength than either of the other two materials. Moreover as time goes by, through the absorption from the air of carbon dioxygen in chemical combination, it grows constantly stronger and harder, with the result that the cost

of maintenance is practically a negligible factor. Being denser and freer from porosity, it has greater waterproof qualities, but the greatest virtue of concrete is that it is a poor conductor of heat, and therefore, at all times preserves the grain contents of a tank at a more uniform temperature, and completely protects it in case of fire.

Brick, theoretically, is a good material with which to build tanks, but practically it is ordinarily found to be too costly, and in addition, in order to use commercial sizes, the walls have to be made so thick that they occupy too much valuable ground space.

Tile is an admirable material for roofs, floors and for fireproofing structural steel and in addition has been employed to a considerable extent for grain tanks. A single piece of tile will stand greater compression than a piece of concrete of similar dimensions, and possesses equal fire resisting qualities, but because tile is made with hollow spaces surrounded by thin walls embedded in mortar, the resulting construction is not nearly so strong as a homogeneous concrete wall. As compared with concrete, the chief disadvantage found in the use of tile is that is practically impossible to build a grain elevator of this material and have it absolutely waterproof, and the periodical repointing and repainting of tile tanks which has been found necessary to keep out the elements, is very expensive, and a strong argument to show why this type of construction will lose whatever popularity it now possesses. Already several concrete additions to existing tile elevators have been built, and many owners of tile tanks have abandoned this type of construction for concrete.

The comparative cost of elevators built of steel, tile, brick and concrete depends entirely upon the design of the elevator and the locality in which it is situated. Steel, tile and brick often have to be hauled long distances from the factories where they are made, which involves a large freight expenditure, whereas sand, crushed stone and gravel are found almost everywhere in nature in sufficient quantity and quality, and cement, though manufactured, is now made in widely

scattered places and can be secured cheaply and promptly. And as in addition, less skilled labor is required in concrete construction than in either steel, brick or tile, it results that the former, except in extraordinary cases, is found to be decidedly the cheapest.

There are several large and costly elevators that have been built in recent years which are monuments to the ignorance and contempt for science of the men who are responsible for their design. Inherent mistakes in choosing the essential elements of the design were made which could not later be remedied, because the cost would be out of proportion to their value. Either the working house was to wide and lacking in spouting height, or the bins were too big for the average business, or the hoppers were too flat to clean out without hand labor. In other houses distributing and cleaning stories that should have been put in were not provided for. Scale hoppers and car pits were not large enough, or were spaced too closely for the modern car.

In a notable elevator built within the last four years, the receiving capacity was less than one-half of what the contract called for. The machinery could elevate the grain, but the tracks and car-pits were inadequate for unloading. Such mistakes are mistakes of arrangement, but there are others of a structural nature that result in actual failure of strength and are followed by disaster. The following are a few instances of this character: One well-known steel elevator with its contents of one-half million bushels of wheat fell, because of defective foundations, into the river, entailing a loss of several hundred thousand dollars. In another elevator the concrete bottoms burst and the steel walls buckled the first time they were filled with grain. They were afterwards reinforced at a great expense, but the result will always be unsatisfactory and unsightly. Another case is of a large well known wooden elevator which had its entire lower construction of posts, bin bottoms and girders taken out, for it had occured to the builder that it would be a good idea

to fireproof the wood with sheet iron, but dry rot ensued and almost ruined the house.

While losses and disasters have on the one hand resulted from ignorance of engineering principles, it has on the other hand developed that too much stress has been laid upon theories, resulting in elevator plans too elaborate, too cumbersome, and consequently wasteful of material and money.

Progress in construction of concrete bins for grain storage was retarded for several years by the bursting of several large concrete grain elevators. A notable example of one failure was a concrete grain elevator located at Springfield, Ills., as the grain was withdrawn from the bin it left almost a perfect vacuum within the bin, thus creating an enormous outside pressure on the wall, which caused its failure. Examination of the drawings for this particular elevator show that the engineer in charge had carelessly neglected to consider this force. Reliable contractors may be thoroughly depended upon to build a structure which in every way will be strong enough to withstand every possible chance of failure. There are now in the elevator business, at least a half dozen concerns who have made a specialty of concrete elevators and may be thoroughly relied upon. Among this list may be noted James Stewart & Company, John S. Metcalf Company, McDonald Engineering Company, Stevens Engineering Company, and Burrell Engineering Company.

OPERATION OF HANDLING GRAIN IN A GRAIN ELEVATOR.

Grain is delivered to the elevator in two ways: namely, by means of boat or by means of railroad cars, however in small country towns grain is delivered to the elevator by means of wagons. We shall first consider the delivery of grain by boat.

The reception of the grain by the elevator is carried on through a marine tower, which is a tall and usually square building, constructed of concrete or steel, but preferably of concrete. The marine tower essentially consists of a leg which by means of machinery, is lowered down into the hold of the boat to receive the grain. It might be stated that a leg is an enclosed belt conveyor on which is attached steel buckets, by means of which, when set in motion delivers the grain to the marine tower. As the grain is withdrawn from the boat it gradually rises, but the elevator leg is so constructed that it can be adjusted for any position of the boat. From the elevator leg the grain is spouted into a garner and then into a scale where it is weighed, from which it is spouted onto a belt conveyor, which in turn delivers the grain to the elevator, where it is received by the receiving leg and hence lofted to the top of the elevator and spouted into a garner, then into a scale where it is weighed, whence it is delivered into its proper bin. Some marine towers, however, do not contain a scale, as the scale is placed in the elevator and the weighing done there.

Next let us consider the reception of grain by railroad cars. In connection with large elevators it is customary to run two or three tracks, and as many as six alongside of the elevators, the tracks being ordinarily 16 ft. centers. Under the tracks are constructed steel receiving hoppers, of a capacity varying from 500 or 600 bushels to 2000 bushels. These hoppers are provided with

interlocking slides which are operated from the track level and enables the grain operator to regulate the delivery of the grain from the receiving hoppers onto the conveyor belt, which is located underneath the steel hoppers, which delivers the grain to the elevator leg, whence it is lofted to the top of the elevator, spouted into the garner and weighed in a scale located directly below the garner, from whence it is delivered by means of a Mayo spout to its proper bin. The car is placed over the receiving hoppers and the door of the car broken in, allowing the grain to fall through the steel gratings which are placed on a level with the track into the hoppers. The breaking of the door however, does not by any means discharge all the grain, but by means of an improved device, known as the Clark Grain Shovel, it is possible to scrape the remaining grain from the car in a very short time. It might be stated here to give the reader an idea of how swiftly a car can be unloaded, that a car of grain containing 2000 bushels can be unloaded in fifteen minutes, or at the rate of 80,000 bushels in a ten hour day.

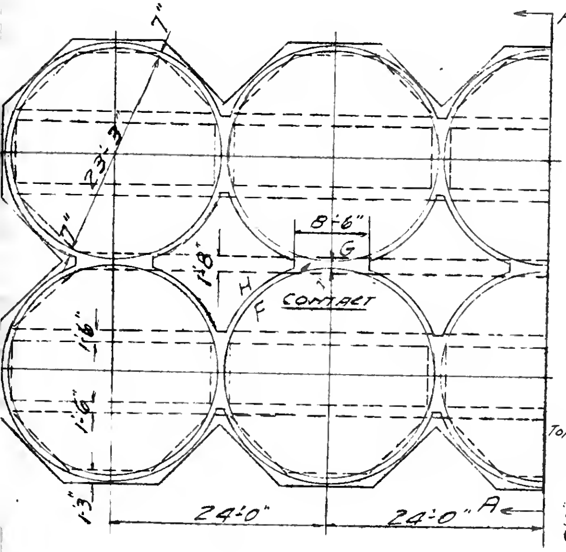
When the grain is ready for shipment, it is drawn from the bins by means of a loading spout, which delivers the grain directly to a shipping leg or indirectly by means of a screw conveyor or a belt conveyor. The shipping leg lofts the grain to the top of the elevator, delivers it into the garners, hence into the scales where it is weighed and then transferred by means of a car spout into the car or a dock spout into the boat. It might be stated here what is meant by the term garner. A garner is nothing but a bin located above the scale. It is provided with a series of discharge valves, which when opened, deliver the grain into the scale in less than two minutes. When the scale is filled thedischarge valves are shut and the grain weighed , hence delivered to its destination. It well be noted here that the garner serves the purpose of collecting the grain while weighings are being made and in this way the grain may be received or shipped in a steady stream without any interruptions.

The operation of grain as above described is a description of handling

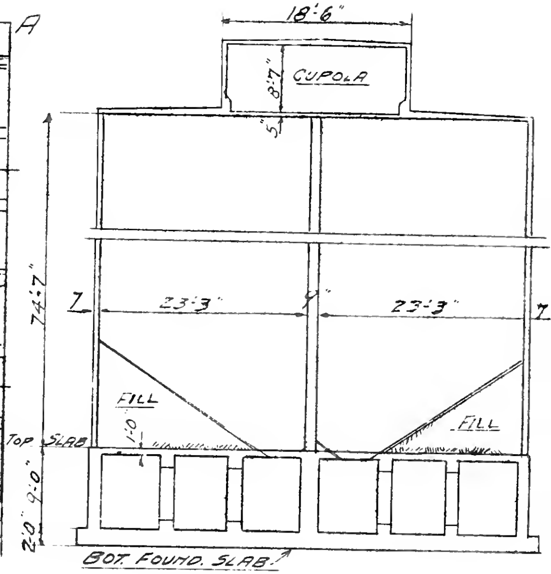
of grain in what is termed a transfer house, which is a means of transferring the grain from one railroad to another or from a railroad car to a boat or vica versa. There are other kinds of elevators, in which the grain is prepared for milling and other commercial usages. The grain as received from the farmers contains a lot of foreign material, such as straw, sticks and stones and it also contains as high as 15% moisture. To clean the grain and to separate the various kinds of grain from one another, it becomes necessary to run the grain through such machines as screeners, separators and scourers. These machines, however, vary according to the kind of grain which is handled. To remove the moisture from the grain it is necessary to heat the grain in what is termed a druer house, in which the grain is heated and retained at a sufficient temperature to remove the moisture, to within 1 or 2%. After the grain has undergone this special treatment it is conveyed into its proper bin to wait for further shipment.

= DESIGN OF CONCRETE GRAIN ELEVATOR =

CALCULATIONS



PLAN OF TANKS AND FOUNDATION WALLS



CROSS SECTION A-A

THE FIRST DRAWING ORDINARILY MADE IN PRACTICE IS THE FOUNDATION PLAN; THIS INVOLVES THE FIGURING OF THE LOADING, WHICH IN TURN REQUIRES THE DETERMINATION OF THE SIZE OF TANK WALL AND THICKNESS OF TOP AND BOTTOM FOUNDATION SLABS.

~ TANK WALLS ~

FROM A PRACTICAL VIEW POINT TANK WALLS ARE SELDOM MADE LESS THAN 6" IN THICKNESS, AND FOR ORDINARY HEIGHT OF TANKS, 70'-0 FT., A MIN BEARING

VALUE OF 350# IS OBTAINED.

HEIGHT OF TANK WALLS = 95'-0"

ASSUME THICKNESS OF TANK WALLS - 7"

LEN. OF CONTACT = 8'-6"

SECTIONAL AREA OF TANK = AREA OF OUTSIDE CIRCLE - AREA OF INSIDE CIRCLE = 468.23 - 424.56 = 43.7 SQ. FT.

WT OF WALL = 43.7□' × 95' × 150# = 625 000#

GRAIN WALL LOAD = WT. OF GRAIN - VERTICAL GRAIN LOAD.

WT. OF GRAIN IN TANK = 30600 BU. @ 60# = 1 836 000#

VERTICAL GRAIN LOAD = $V = 58.7\,DA\left[1 - \frac{1}{2.7183^{.852\frac{H}{D}}}\right] =$

$58.7 \times 23.25 \times 424.56\left[1 - \frac{1}{2.7183^{.852 \times \frac{95}{23.25}}}\right] = 561\,189^{\#}$

GRAIN WALL LOAD = 1836000# - 561 189# = 1 274 811#

WT OF CUPOLA OVER TANKS = 424.56□' × 100# = 42456#

TOTAL LOAD ON TANK WALL = 625000# + 1274811# + 42456# = 1942 267#. 1942267 ÷ 43.7□' × 144 = 309#/SQ. IN.

ON TANK WALLS ADJACENT TO INTERSPACE THERE IS AN ADDITIONAL GRAIN LOAD DUE TO GRAIN IN INTERSPACE.

WT. OF GRAIN IN THE INTERSPACE = 8250 BU. @ 60# = 495000#

SECTIONAL AREA OF INTERSPACE WALLS = 104.77 SQ. FT.

CIRCUM. OF INTERSPACE = 48.67□'

HYDRAULIC RADIUS = 104.77 ÷ 48.67 = 2.15

KNOWING THE HYDRAULIC RADIUS THE SIDE OF A SQUARE OR DIAM. OF A CIRCLE CAN BE FOUND WHICH WILL GIVE SAME GRAIN PRESSURES AS FOR INTERSPACE.

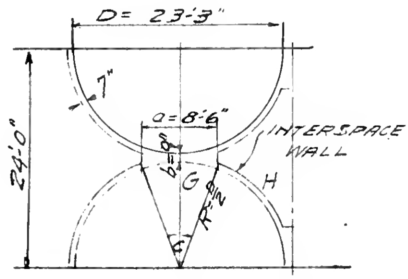
$r = 2.15 = \frac{D}{4} \qquad D = 8.6$

$V = 58.7 \times 8.6 \times 104.77\left[1 - \frac{1}{2.7183^{.852 \times \frac{95}{8.6}}}\right] = 52700^{\#}$

GRAIN WALL LOAD = 495000# - 52700# = 442300#

$\frac{442300}{43.8 \times 144} = 70^{\#}$. TOTAL LOAD ON INTERSPACE (F) = 309# + 70# = 379#

A BEARING VALUE ON TANK WALLS OF 379# PER SQ.IN. IS NOT EXCESSIVE, THEREFORE WALL OF 7" THICKNESS IS AMPLE. THE CENTER CONTACT (G) MUST NOW BE INVESTIGATED, FOR LOAD ON CONTACT IS GREAT THAN ON WALL BECAUSE IT IS ASSUMED THAT WALL MARKED H ARCHES FROM CONTACT TO CONTACT. THIS ASSUMPTION IS NECESSAR[Y] SINCE A WALL UNDER TANK WALL H CANNOT BE PROVIDED FOR, BECAUSE OF THE TUNNEL CONTAINING THE 36" CONV. BELT.



PLAN OF CONTACT

AREA OF CONTACT IS GIVEN BY THE FOLLOWING FORMULA:

$$A = a\left(b + D - \tfrac{1}{2}\sqrt{D^2 - a^2}\right) - C^{\circ}R^2 \times .004$$

$$\sin\frac{C}{2} = \frac{a}{D}$$

$$\sin\frac{C}{2} = \frac{8.5}{23.25} = .366 \qquad C = 43^{\circ}$$

$$A = 8.5\left(.75 + 23.25 - \tfrac{1}{2}\sqrt{23.25^2 - 8.5^2}\right) - 43^{\circ} \times \overline{23.25}^2 \times .00436 = 10.19^{\square'} = 166$$

TOTAL LOAD CONTACT (G) = $\dfrac{1942267^{\#} + 442300^{\#}}{2}$ – LOAD FOR WHICH TOP SLAB IS DESIGNED FOR.

AS SHALL BE SEEN LATTER, TOP SLAB OF FOUNDATION IS GOOD FOR 2050# SQ.FT. TOTAL AREA OF TANK WALL RESTING ON TOP SLAB, UNSUPPORTED BY FOUNDATION WALL EQUAL 11.8□'. 11.8 × 2050# = 24200#.

THUS TOTAL LOAD ON CONTACT (G) = [(1942267# + 442300#) ÷ 2] – 24200# = 1180183#

PRESSURE PER SQ.IN ON CONTACT = 1180183# ÷ 1667.3□" = 708# WHICH IS ALLOWABLE.

DESIGN OF TOP FOUNDATION SLAB

VERTICAL GRAIN PRESSURE AS DETERMINED ABOVE FOR 23'-3" DIAM. TANK = 1322#□'

AVERAGE DEPTH OF FILL IN TANK = 5.8 FT. @ 100# SQ. FT. = 580#

WT OF 12" SLAB = 150# SQ. FT.

TOTAL LOAD ON SLAB = 1322 + 580 + 150 = 2052# SQ. FT.

BENDING MOMENT = $\frac{2052 \times \overline{6.5}^2}{8} =$ 10 850 FT. LBS.

$M = .86\,PSBD^2 = .86 \times .008 \times 16000\,BD^2 = 110\,BD^2$

$M = 10850 = 110\,BD^2 \quad D = 9.9''$ MAKE 12" SLAB

AREA OF STEEL = $9.9 \times 12 \times .008 = .945\,\square''$ USE $\frac{7}{8}\phi$ $7\frac{1}{2}$ CTS.

DESIGN OF BOTTOM FOUNDATION SLAB

THE BEARING ON BOT. SLAB = 6500# SQ. FT. AS WILL BE SHOWN LATE

$$M = \frac{6500 \times \overline{6.5}^2}{8} = 34300 \text{ FT. LBS.}$$

$M = 110\,BD^2 = 34300. \quad D = 17.7''$ GIVING A TOTAL DEPTH OF 21". SINCE THIS SLAB IS LAID DIRELTLY ON THE GROUND A UNIFORM THICKNESS WILL BE HARD TO OBTAIN. TO MAKE SUCH OF AN EFFECTIVE DEPTH OF AT LEAST 18" THE SLAB WILL BE MADE 24" THICK.

- PILING FOR TANKS -

LOADING FOR AREA MARKED L-L

GRAIN IN TANK - 30600 BU. @ 60#	1836000#
" " INTERSPACE - 8250 BU. @ 60#	495000
FILLING IN TANK - 2500 CU FT. @ 100#	250000
" " INTERSPACE - 600 CU FT @ 100#	60000
WT. OF TANK WALLS	625000
TOP FOUNDATION SLAB - 24'x24 x 1'x 150#	86400
BOTTOM " " - 24'x24'x 2 x 150#	173000
CUPOLA - 24'x 24' x 100#	57600
FOUNDATION WALLS - 1180 CU. FT. @ 150#	172000
TOTAL LOAD	3754000#

BEARING VALUE OF GROUND 1.2 TONS = 2400# SQ. FT.

375400 ÷ 576 = 6500# SQ FT. = REQUIRED BEARING.

SINCE REQUIRED BEARING EXCEEDS THE ALLOWED BEARING PILES MUST BE USED. VALUE OF PILE = 16 TONS = 32000#

3754000 ÷ 32000 = 117 PILES REQUIRED

32000 ÷ 6500 = 4.9 SQ. FT. SUPPORTED BY EACH PILE

SPACE PILES 2'-2" & 2'-3" CTRS.

LOADING FOR AREA MARKED N-N

GRAIN IN HALF TANK 15300 BU. @ 60#	918000
FILL IN " " 1250 CU FT. @ 100#	125000
WT OF TANK WALL	312500
TOP FOUND. SLAB - 247□' x 1' x 150#	37050
BOT. " " 290□' x 2' x 150#	87000
FOUNDATION WALLS 690 CU. FT @ 150	103500
CUPOLA - 235□' x 25#	5900
TOTAL LOAD -	1587950#

1587950 ÷ 32000 = 50 PILES REQ.

1587950 ÷ 290 = 5450# PER SQ. FT.

32000 ÷ 5450 = 5.9□'

5.9 x 2.25 = 2.61 = 2'-7". SPACE PILES 2'-3" & 2'-7"

PILING FOR WORKHOUSE

LOADINGS

WALL - .75 x 11' x 32' x 150#	39700#
WALL - .58 x 127.5 x 95 x 150	105000
" - .75 x 118 x 32 x 150	425000
2 " - .75 x 118 x 16 x 150	425000
ROOF - 32 x 168 x .42 x 150	34000
6 FLOORS - 30 x 15 x .5 x 150	202800
PILASTERS - 1.5 x .5 x 118 x 150	13300
" 6 x 2 x .41 x 118 x 150	87000
BEAMS - 6 x 2 x 1 x 14.6 x 150	26300
GARNER WALL .67 x 14 x 14.5 x 150	20400
" BEAMS 2 x 3 x 1.5 x 14.5 x 150	19600
FOUND. WALL - 1.5 x 13 x 16 x 150 x 2	93500
" " - 1.5 x 13 x 29 x 150	82000
SLAB - 2 x 32 x 14 x 150	134500
DUE TO INCREASE HEIGHT OF W.H	280000
2 LEGS	14000
1 SCALE - 17000#. 1 AUTO SCALE 3000#. CLEANER 6000#	26000
ST. GARNER BOTTOMS	4000
GRAIN IN SCALE & GARNER	240000
CIRCULAR STAIRS - 100' @ 100#	10000
STRUCTURAL STEEL	34000
SPOUTING	4000
MOTORS	20000
LIVE LOAD - 1700 SQ. FT. @ 20#	54000
MACHINERY	40000
TOTAL	2,434,100#

2434100 ÷ 32000 = 76 PILES REQUIRED

2434100 ÷ 544 = 4500# SQ. FT.

32000 ÷ 4500 = 7.1□' SUPPORTED BY EACH PILE

FOUNDATION SLAB WORKHOUSE

BEARING ON SLAB = 4500# - WT. OF SLAB + WATER PRESSURE

ASSUMED SLAB 2'-0" @ 150 = 300#

WATER PRESSURE 1'-0" HEAD = 62#

4500 - 300 + 62 = 4262# SQ. FT.

$$\text{BENDING MOMENT} = \frac{4262 \times \overline{14.25}^2}{8} = 107500 \text{ FT. LBS.}$$

$M = 110BD^2 = 107500$ $D = 31.25"$ TOTAL DEPTH = 36"

31.25 x 12 x .008 = 3.14□" OF STEEL REQUIRED

USE 1"φ SPACED 3" CTRS.

TANK REINFORCING

WHEN TANK IS FULL OF GRAIN, THE GRAIN TENDS TO PUSH THE TANK WALLS OUT. SINCE CONCRETE CAN NOT BE FIGURED FOR TENSION, STEEL BARS MUST BE USED.

$$\text{LATERAL GRAIN PRESSURE} = 58.7D^2\left[1-\frac{1}{2.7183^{.852\frac{H}{D}}}\right].6$$

SUBSTITUTING VALUES OF D & H IN EQUATION, THE LATERAL PRESSURE CAN BE FOUND FOR ANY DEPTH OF GRAIN.

D = DIAM. OF BIN.

H = DEPTH OF GRAIN.

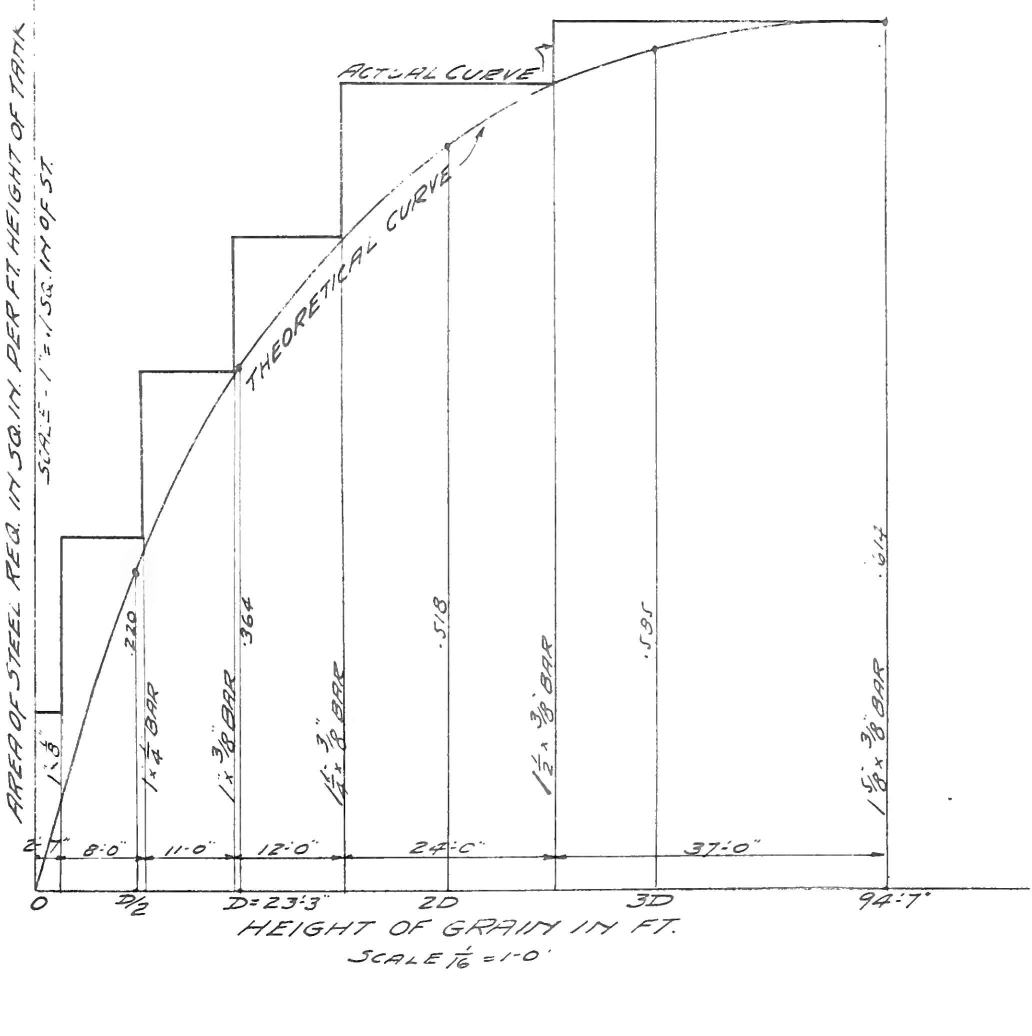
		AREA STEEL REQ. PER FOOT OF TANK = L ÷ 30000
$\frac{H}{D}=\frac{\frac{1}{2}D}{D}=.5$	$L = 6605^{\#}$	$.220^{\square''}$
$\frac{H}{D}=\frac{D}{D}=1.0$	$L = 10913^{\#}$	$.364^{\square''}$
$\frac{H}{D}=\frac{2D}{D}=2.0$	$L = 15577^{\#}$	$.518^{\square''}$
$\frac{H}{D}=\frac{3D}{D}=3.0$	$L = 17557^{\#}$	$.585^{\square''}$
$\frac{H}{D}=\frac{94.58}{23.25}=4.07$	$L = 18460^{\#}$	$.614^{\square''}$

VALUE OF L = TOTAL LATERAL PRESSURE AND IS TAKEN UP BY ST. REIN. ON BOTH SIDES OF TANK. SINCE ST. IS GOOD FOR $15000^{\#}$, THE AREA REQ. OF STEEL IS EQUAL TO L ÷ 2×15000

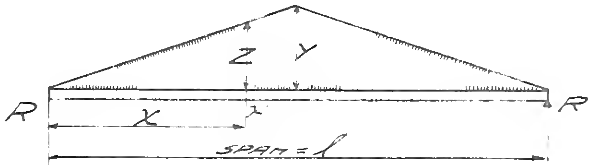
USING DEPTH OF GRAIN H AND CORRESPONDING ST. AREA AS ABSCISSA & ORDINATES RESPECTIVELY A CURVE CAN BE PLOTTED FROM WHICH THE TANK REINFORCING CAN BE DETERMINED.

SEE CURVE ON NEXT PAGE

DIAGRAM SHOWING THEORETICAL & ACTUAL AMT. OF STEEL IN TANKS



DESIGN OF CUPOLA ROOF



SKETCH SHOWING CONDITION OF CUPOLA ROOF LOAD

DERIVATION OF FORMULA FOR BENDING

$R = \frac{l}{2} \times y \times \frac{1}{2} \times w = \frac{lyw}{4}$. W = WT. PER SQ. FT OF THICKNESS.

VALUE OF Z. $\frac{x}{\frac{l}{2}} = \frac{z}{y}$. $z = \frac{2xy}{l}$.

MOMENTS AT SECTION X: $M = \frac{lyw}{4}x - \frac{2xy}{l} \times \frac{x}{2} w \frac{x}{3} =$

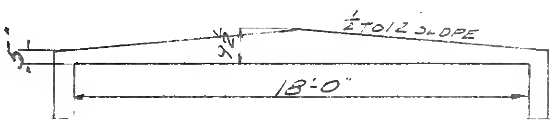
$$\frac{lywx}{4} - \frac{x^3yw}{3l} \qquad ①$$

$$dM = \frac{lyw}{4} - \frac{3x^2yw}{3l} = 0$$

$$\therefore x = \frac{l}{2}.$$

SUBSTITUTING VALUE OF $x = \frac{l}{2}$ IN EQUATION ①

$$M = \frac{3l^2yw}{24} - \frac{l^2yw}{24} = \frac{l^2yw}{12}.$$



SECTION THRU ROOF

DEAD LOAD - CONCRETE @ 150# CU.FT. ROOFING @ 6 1/2# SQ.FT.
LIVE LOAD - 20# SQ.FT.

$M = \frac{\overline{18}^2 \times .373 \times 150}{12} = 1510$ ft.#

$M = \frac{\overline{18}^2 \times 89}{8} = 3610$ ft#

TOTAL M $= 5120$ ft#

$M = 110BD^2 = 5120$ ft#

$D = .6.75"$

AREA ST $= 12 \times 6.75 \times .008 = .647$□"

USE 1/2" Ø - 4" CTRS.

END REACTION

LIVE LOAD - $18.5 \times 20^{\#}$ = 370
ROOF COVERING - $18.5 \times 6.5^{\#}$ = 120
CONCRETE - $\frac{(9\frac{1}{2}+5)}{12} \frac{1}{2} \times 18.5 \times 150^{\#} = 1680$
$2070^{\#}$/LINEAR FT.

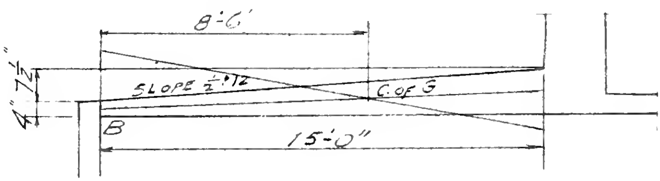
END REACTION = $\frac{1}{2} \times 2070 = 1035^{\#}$

ALLOWED SHEAR = $50^{\#}$

$\frac{1035}{50} = 20.7^{\square}$" REQ. $\frac{20.7}{12} = 1.72" + 1\frac{1}{2}" = 3.22"$ DEPTH AT SUPPORT

SINCE NO GIRDERS ARE USED IN ROOF, IT WILL BE MADE 5" AT SUPPORT TO MAKE RIGID ON ACCOUNT OF WIND.

DESIGN OF TANK ROOF



LIVE LOAD - $15' \times 20^{\#}$ = $300^{\#}$
ROOF COVERING $15 \times 6\frac{1}{2}^{\#}$ = $97.5^{\#}$
CONCRETE $\frac{(4 \times 11\frac{1}{2})}{12} \frac{1}{2} \times 15 \times 150^{\#}$ = $1450.0^{\#}$
TOTAL WT OF ROOF = $1847.5^{\#}$

SHEAR AT END B

$B \cdot 5 = \frac{1450.^{\#} \times 6.5}{15}$ B = $627^{\#}$ CONCRETE REACTION
$150^{\#}$ L.L.
$48.7^{\#}$ ROOFING
TOTAL REACTION = $825.7^{\#}$

$\frac{825.7}{50} = 16.52$ SQ. IN OF CONCRETE REQ. AT B.
$\frac{16.52}{12} = 1.55" + 1.5" = 3.05"$ DEPTH REQ. AT B. MAKE DEPTH 4"

BENDING MOMENT EQUAL $\frac{1847.5 \times 15}{8} = 3460$ ft.#

$M = 110\,BD^2 = 3460$ $D = 5.6" + 1\frac{1}{2}" = 7.1"$

DEPTH OF ROOF AT CENTER OF SPAN = 7.75". SINCE M. **VARIES** AS THE SQ. OF THE SPAN & SIZE OR DEPTH OF ROOF VARIES AS $\frac{1}{2}$ OF SPAN, THE ABOVE SECTION IS OK.

DESIGN OF TANK ROOF CONTINUED

AREA OF ST. = 12×.008×7.1 = .5375 SQ.IN. USE 3/4" ϕ - 10" CTR.

DESIGN OF TANK ROOF AT QUARTER POINT

L. LOAD = 12'×20# = 240#
ROOFING = 12'×6.5# = 78#
CONCRETE. $\frac{(4+10)}{12}\frac{1}{2}\times12\times150 = 1050$#
TOTAL = 1368#

$M = \frac{1368\times12}{8} = 2050$ ft.#

$M = 110BD^2 = 2050$ D = 4.3" + 1½" = 5.8"

AREA OF ST. = 12×.008×4.3 = .412 SQ.IN. USE 3/4" ϕ - 12" CTS.

DESIGN OF CUPOLA FLOOR OVER TANKS.

SPAN = 8'-0" L.L. = 50#

L.L. = 8'×50# = 400#
CONCRETE. $8\times150\times\frac{5}{12}$ = 500#
900# TOTAL LOAD PER LIN. FT. OF FLOOR.

$M = \frac{900\times8}{8} = 900$ ft.#

$M = 110BD^2 = 900$ D = 2.86 + 1½ = 4.36" MAKE 4½"

AREA ST. = 2.86×12×.008 = .274 □" REQ. USE 3/4" ϕ 12" CTRS.

DESIGN OF CUPOLA FLOOR OVER INTERSPACE

SPAN = 10'-0"
L.L. = 10'×50# = 500#
CONCRETE $10\times150\times\frac{5}{12}$ = 625#
TOTAL = 1125#

$M = \frac{1125\times10}{8} = 1406$ ft.# $= 110BD^2$

D = 3.2" + 1.5 = 4.7 in. MAKE 5"

AREA ST. = 3.2"×12×.008 = .307 USE 3/4" ϕ 12" CTR.

DESIGN OF CUPOLA GIRDER

SPAN = 24'-0"

CUPOLA ROOF	$1035^{\#} \times 24' =$	$24800^{\#}$
" WALL	$-\frac{2}{3} \times 24 \times 150^{\#} \times 5.5 =$	13250
FLOOR	$-4.5 \times \frac{22}{2} \times \frac{5}{12} \times 150^{\#} =$	4000
"	$-$ L.L. $4.5 \times \frac{22}{2} \times 50^{\#} =$	2480
TANK ROOF	$-7.5 \times \frac{22}{2} \times \frac{5}{12} \times 150^{\#} =$	5170
" "	$-$ L.L. $-7.5 \times \frac{22}{2} \times 20^{\#} =$	1650
WT. OF GIRDER	$-24 \times 1.33 \times 2.5 \times 150 =$	11950
	TOTAL LOAD ON GIRDER $=$	$63300^{\#}$

$\frac{63300}{2} \div 50 = 634$ SQ. REQ. FOR SHEAR.

ASSUME GIRDER 1'-3" WIDE. $\frac{634}{15} = 42''$ REQ. DEPTH FOR IF STIRRUPS ARE NOT USED.

GIRDER TO BE DESIGNED AS CONTINUOUS BEAM

$\therefore M = \frac{Wl}{12}$

$M = \frac{63300 \times 24}{12} = 126000$ ft.# = 110 [illegible]

$D^2 = \frac{126600}{110 \times 1.25}$ $\quad D = 30.25'' + 3.75'' = 34''$

AREA ST. $= 30.25 \times 15 \times .008 = 3.425$ □" REQ.

USE 5-1"Ø AT BOT. OF GIRDER.

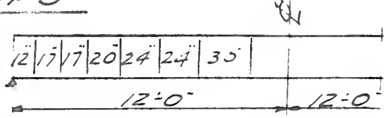
USE 5-1"Ø CONTRA BARS OVER SUPPORTS.

DESIGN OF STIRRUPS

$\frac{31650}{30.25 \times 15} = 70^{\#}$ SHEAR.

$50^{\#}$ TAKEN BY CONCRETE

$20^{\#}$ " " STIRRUPS.



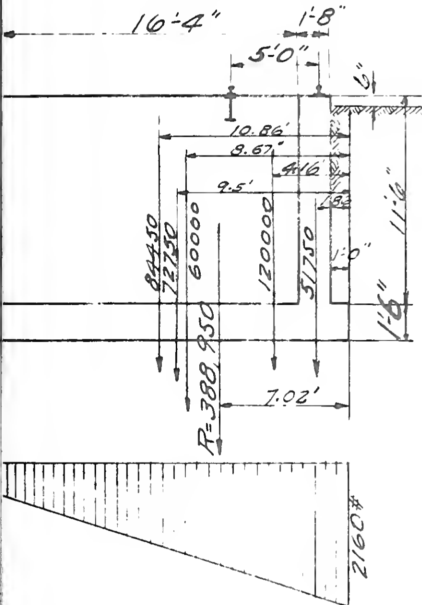
SPACING OF STIRRUPS

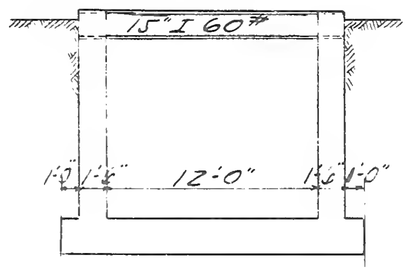
DIAG. TEN. $= 20^{\#} \times 1.4 \times 15 = 420^{\#}$/IN LENG. $\quad 420 \times 12 = 5020^{\#}$/FT. LENG.

As/LIN. FT. $= 5020 \div 16000 = .314$ SQ. IN.

U 3/8"φ $= 4 \times .11 = .442$ □" $\quad 12 \div \frac{.314}{.442} = 17''$ CTRS. - SPACING OF STIRRUPS.

DESIGN OF TRACK REC. PIT.





CROSS SECTION

DETERMINATION OF BEARING ON GROUND

ALLOWED BEARING = $1\frac{1}{4}$ TONS = 2500#/SQ. FT.

2 WALLS	$-16.33 \times 1.5 \times 11.5 \times 150 =$	84450#
1 "	$-15 \times 11.5 \times 1.7 \times 150 =$	51750
SLAB	$-17 \times 19 \times 1.5 \times 150 =$	72750
WT. OF HOPPER + 800 BUS.	=	60000
LOADED CAR. 2000 BU.	=	120000
TOTAL LOAD ON SLAB	=	388950#

$84450 \times 10.86' = 916000$ #/ft.
$72750 \times 9.5' = 692000$
$60000 \times 8.67' = 532000$
$120000 \times 4.16' = 500000$
$51750 \times 1.86' = 96000$

2,736,000

$$\frac{2{,}736{,}000}{388950} = 7.02' \qquad P = \frac{W}{l} \pm \frac{6Wd}{l^2} = \frac{388950}{19} \pm \frac{6 \times 388950 \times 2.5}{19^2} =$$

$20500 \pm 16300 = 36800$# AND 4200#/WIDTH OF PIT.

$36800 \div 17 = 2160$# $4200 \div 17 = 217$#.

DESIGN OF TRACK REC. PIT CONTINUED

$2160 \times \frac{2}{3} = 1460^{\#}$ = BEARING SQ. FT. IN DESIGN OF SLAB.

$\frac{1460 \times \overline{12}^2}{8} = 25600$ ft.# $= 110 BD^2$

$D = 15.3'' + 2.7'' = 18''$

$15.3'' \times 12 \times .008 = 2.3$ □'' ST. REQ. USE $\frac{7}{8}''\phi$ $4\frac{1}{2}''$ CTS.

EARTH PRESSURE

$E = \frac{1}{2} w h^2 \tan^2(45° - \frac{1}{2}\phi)$

$w = 100^{\#}$ CU. FT.

$\phi = 34°$

$h = 11'-0''$

$E = \frac{1}{2} 100 \times \overline{11}^2 \tan^2(45° - \frac{1}{2}34°) = 1706^{\#}$

PRESSURE PER SQ. FT. AT FOOT OF WALL. $X = \frac{1706 \times 2}{11} = 310^{\#}$

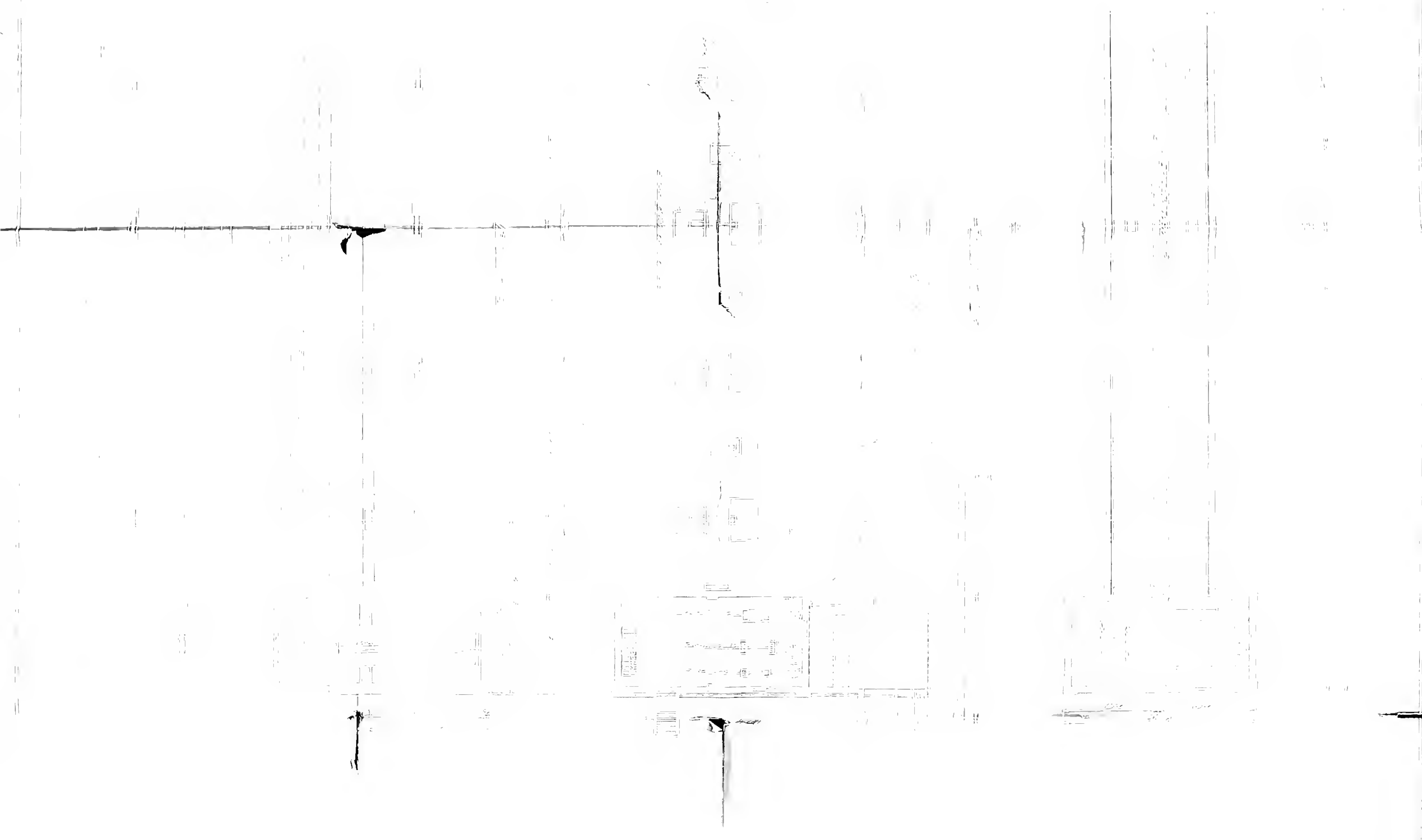
WALL REINFORCING.

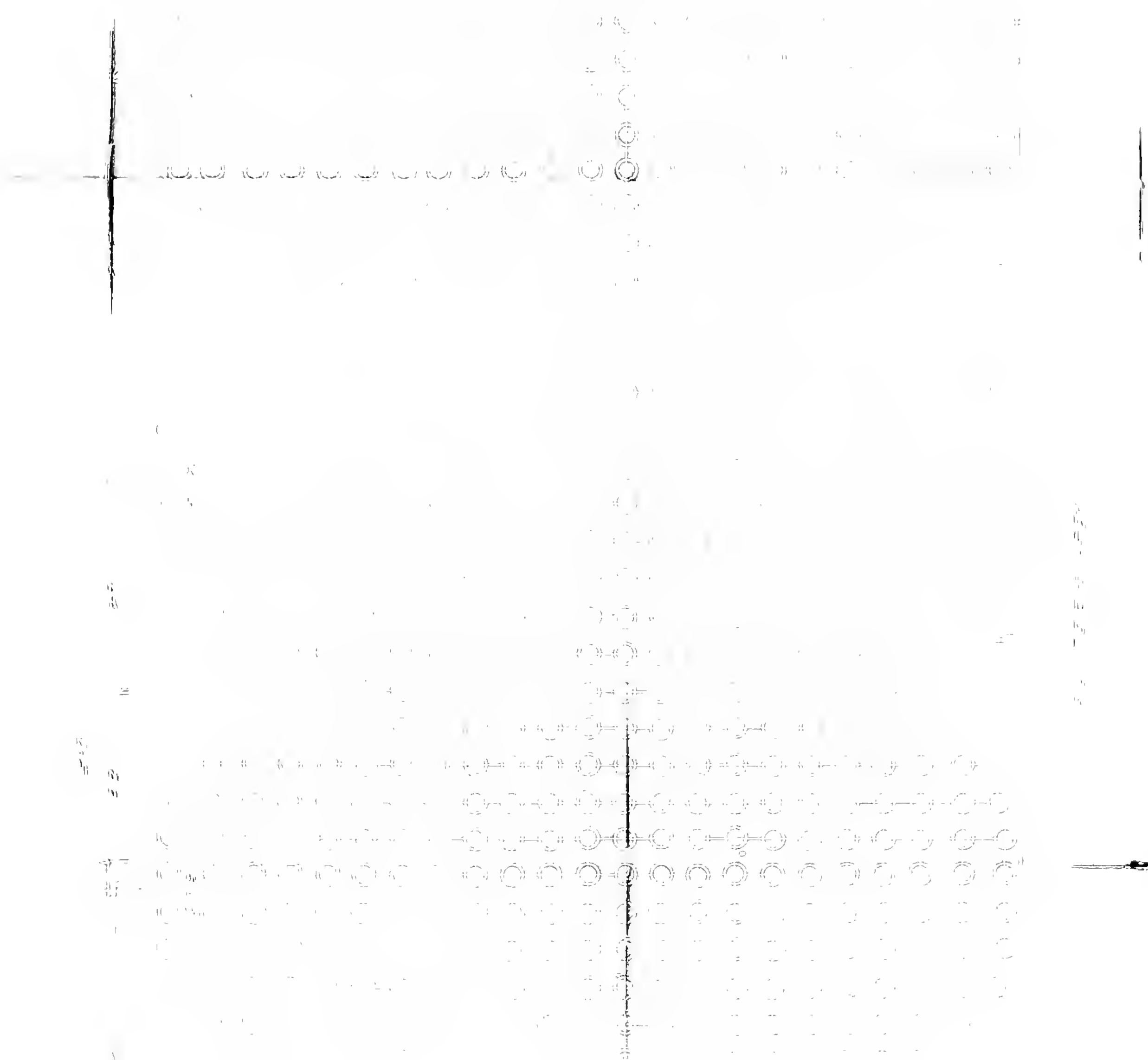
$\frac{310 \times \overline{16.33}^2}{8} = 10300$ FT. LBS. $= M$

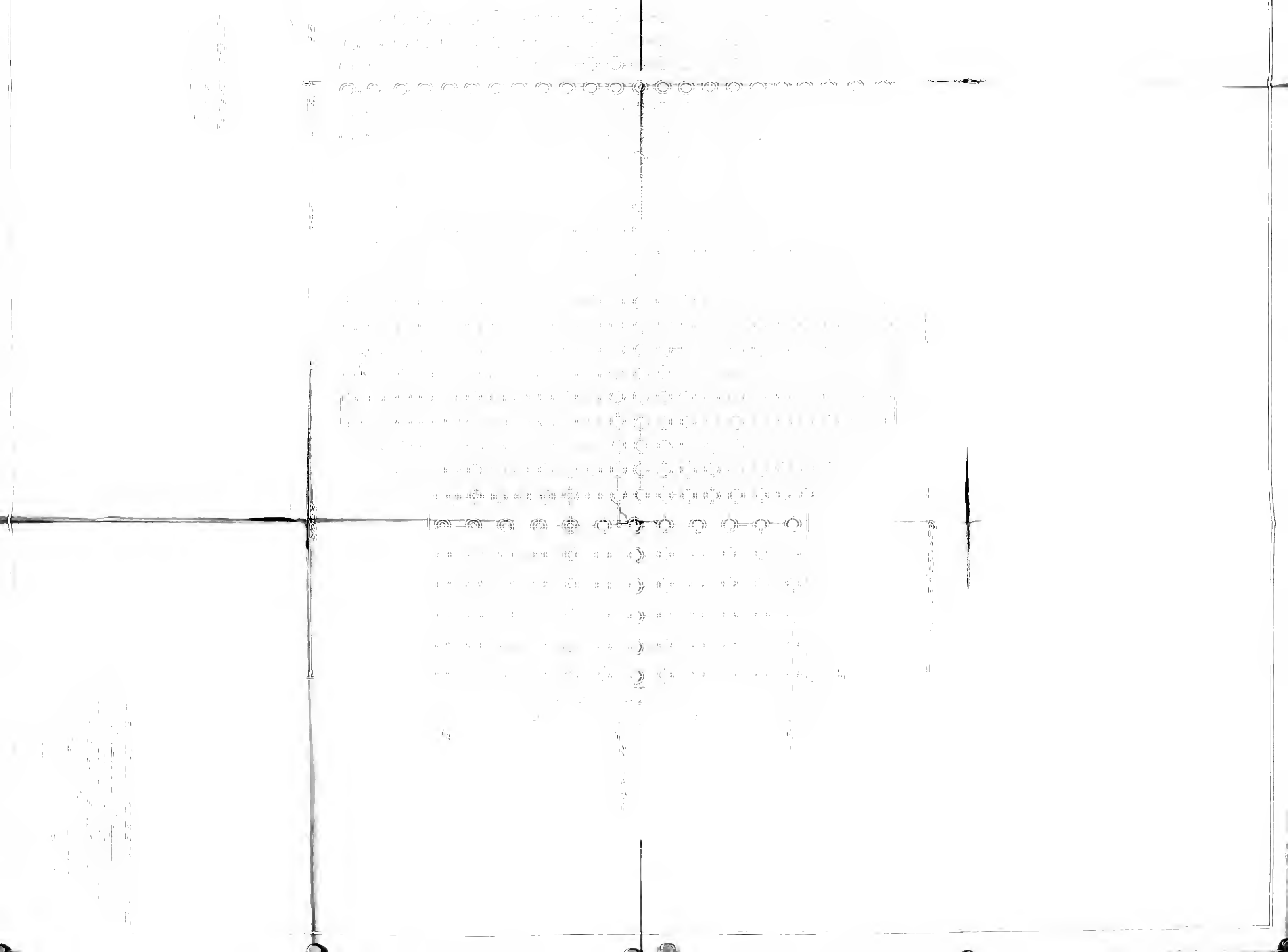
WALL WILL BE MADE 1'-6'' THICK. AND AS VALUE OF M GIVES A THINNER WALL. % REQ. FOR 1'-6'' WALL WILL BE FIGURED - THAT IS % OF STEEL.

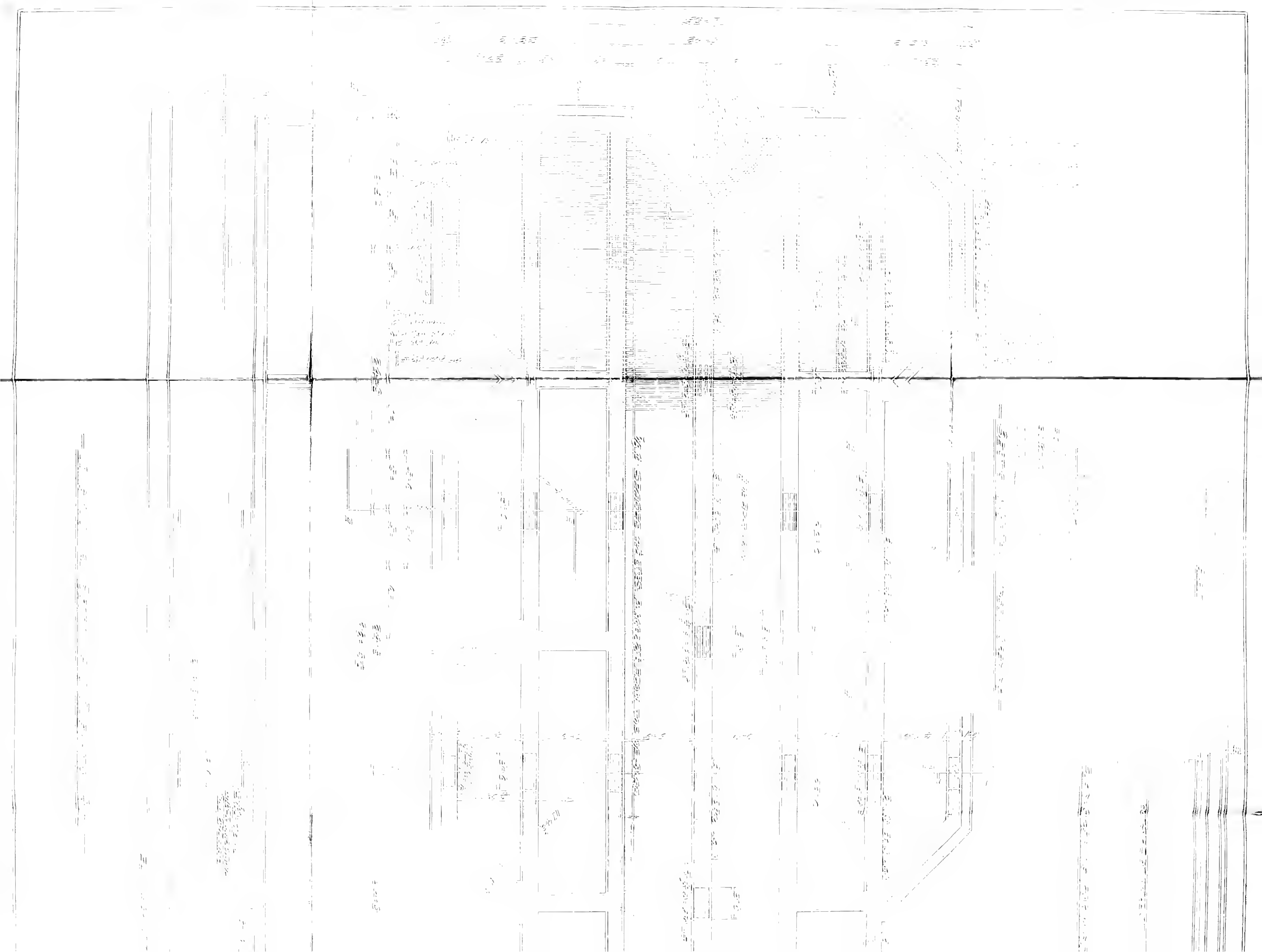
$10300 = .86 P 16000 BD^2$ $P = \frac{10300}{16000 \times .86 \times 256} = .0034$

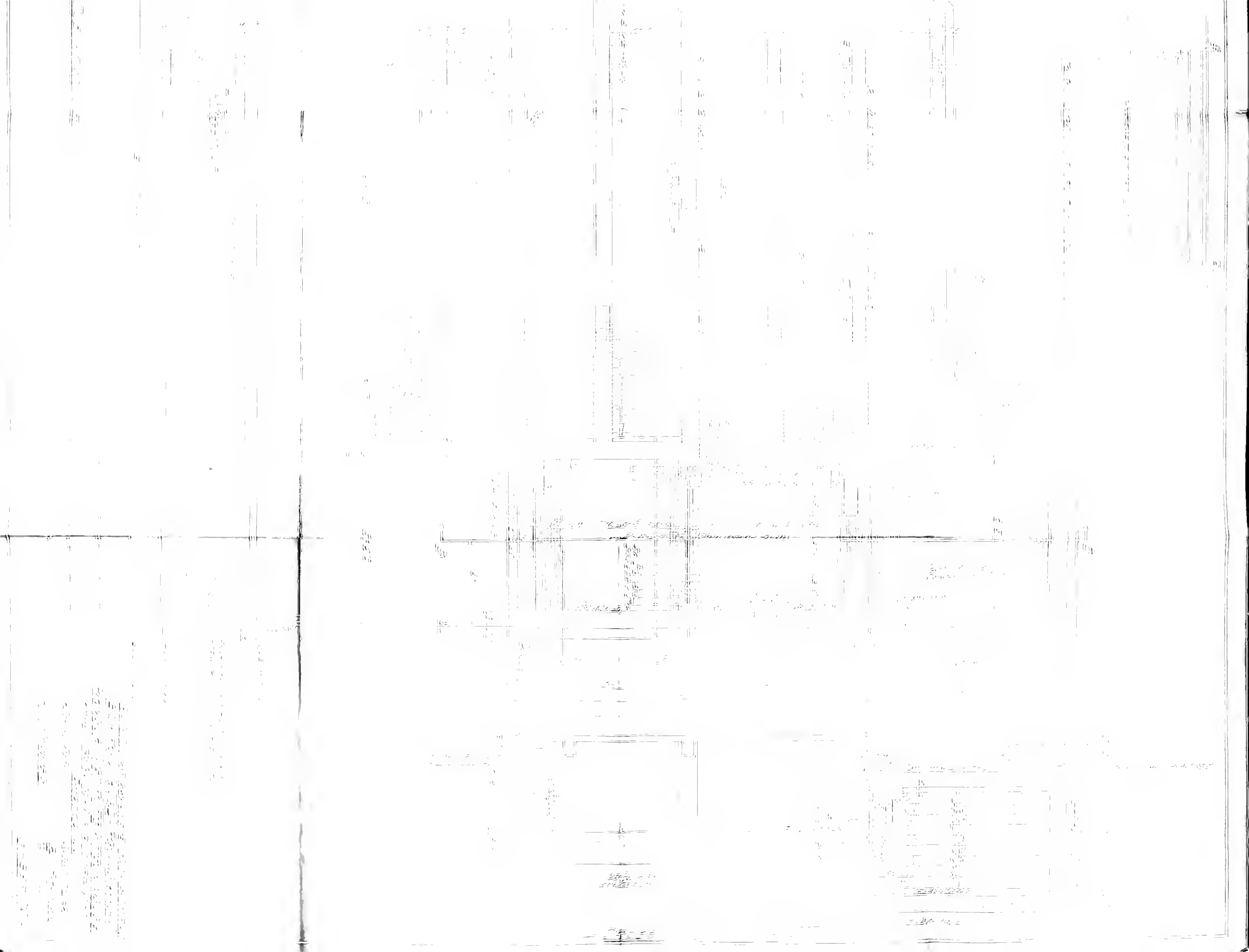
$A_s = 12 \times 16 \times .0034 = .652$ □'' USE $\frac{7}{8}''\phi$ 12'' CTRS.

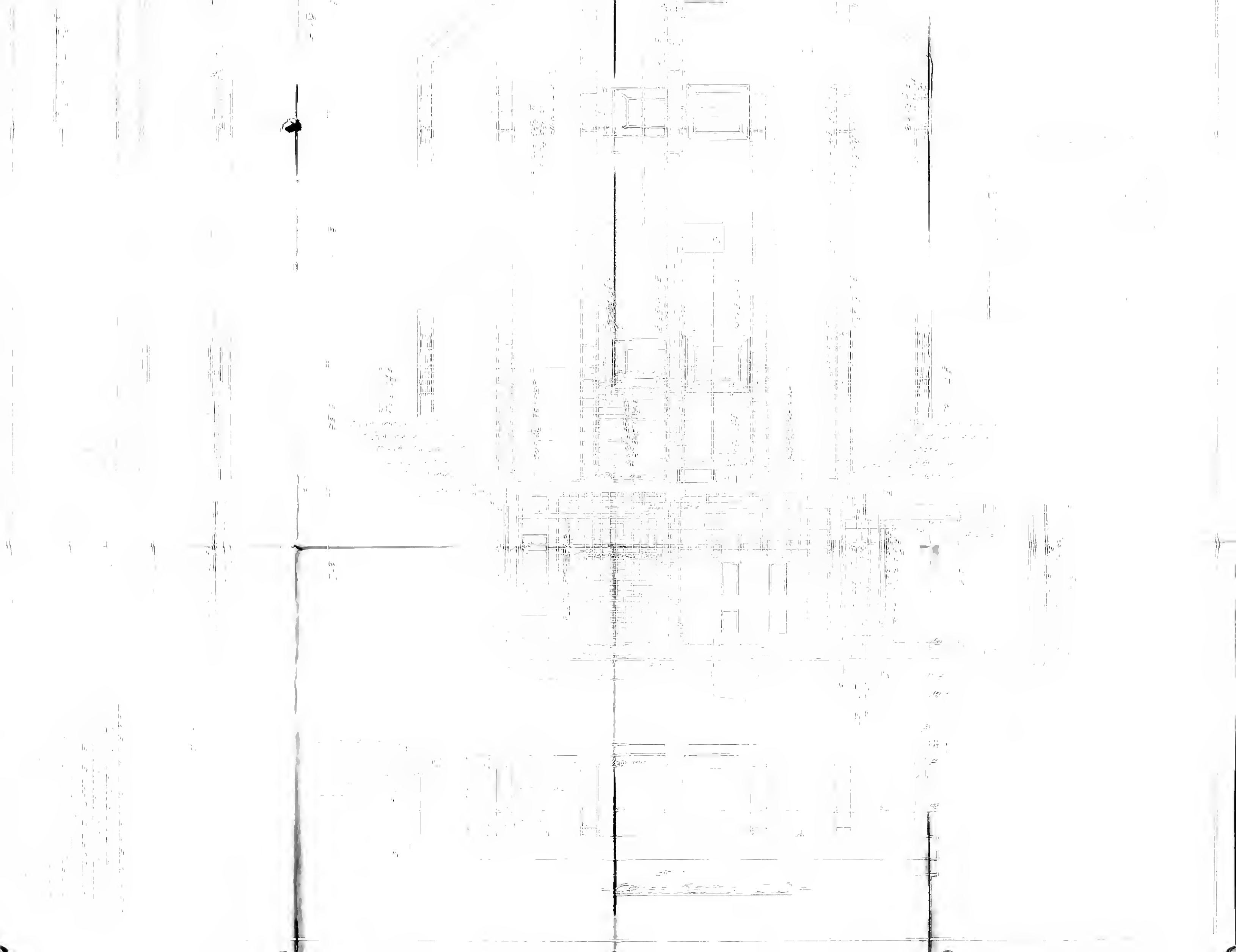


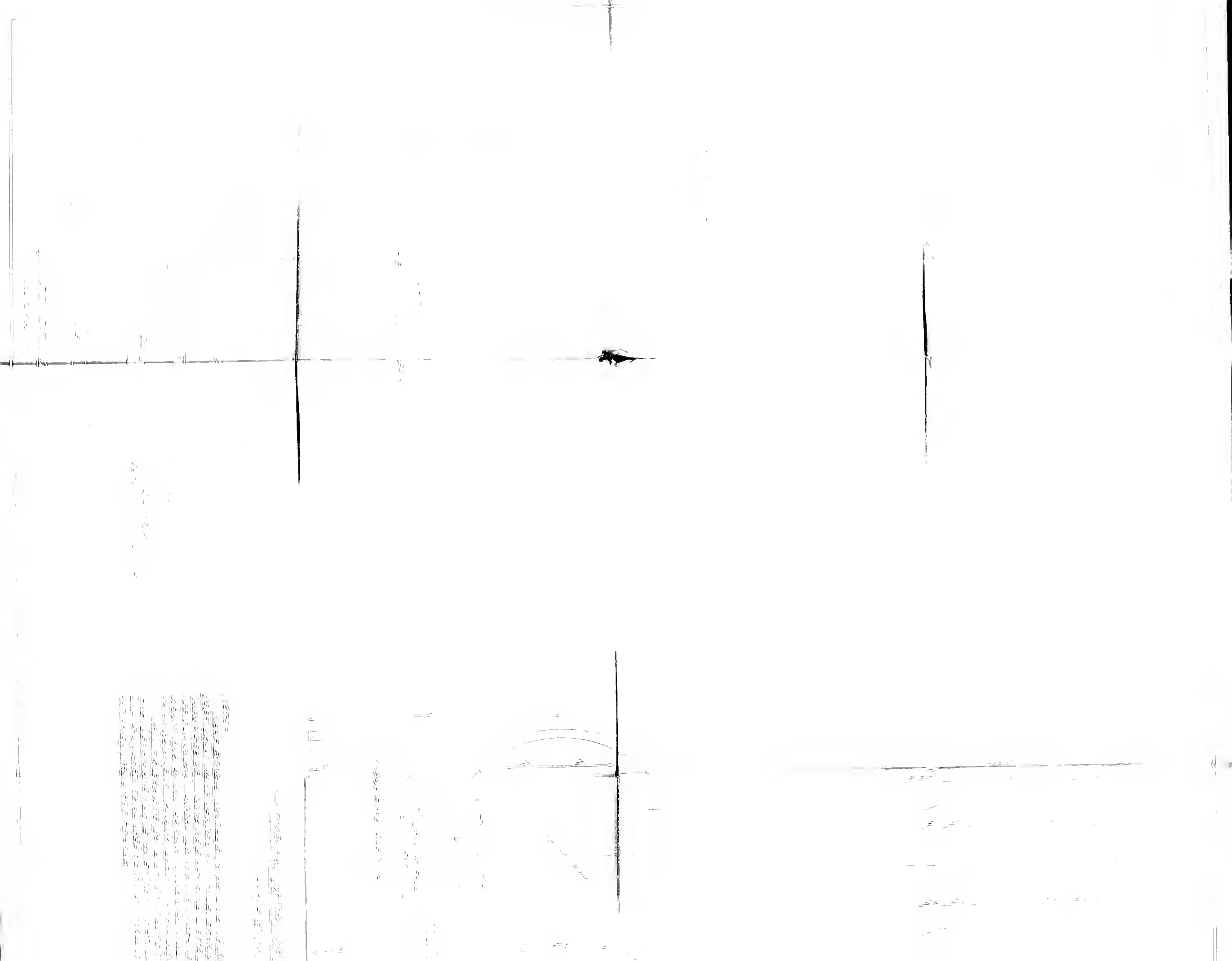












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